The Glass Industry
REG. U. S. PAT. OFF.

Vol. 14 FEBRUARY, 1933 No. 2

Diffusion Combustion and Its Application to Glass Melting

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COMPARED to the spectacular progress in the mechanical working of glass, the art of glass melting has advanced but little since the introduction of air preheating equipment. Economic pressure, aided by better refractories, has pushed melting rates higher, but not without adding to the worries of the furnace man. A variety of designs have been introduced, discarded, forgotten, and invented again; but the glass melter of today is using essentially the same equipment and the same technique that his father used in the old hand plants—and the whole process is veiled in the same mystery.

There have been many things developed to reduce fuel consumption, but nothing to definitely control heat application, convection currents, and reduce refractory deterioration.

Regardless of the diversities which exist in the several branches of the glass industry—differences in methods, processes, equipment, and markets, there is a common ground where all sections meet with equal interest and concern.

That common ground is found in phenomena which are characteristic of, and fundamental to, the manufacturing process of all branches of the industry, and are comprehended in the terms of "glass melting." Obviously, then, this subject touches each of the diverse branches of the industry; it involves a study of the future of the industry in regard to the most vital, intricate and costly of its manufacturing processes.

In the melting of glass batch, composed of sand, soda, lime and other ingredients, into quality glass, we find the same physical agency—namely, heat energy—to be the cause of the metallurgical change. Although the means by which it was applied might differ, this has remained unchanged over a period of years.

Furnace conditions and operation are responsible for the greatest part of the cost of glass manufacturing, not only from the point of fuel expenditure, but from the imperfections in the melt.

A part of the ware has to be passed through the furnace the second time, thus doubling the cost all along the line and necessitating a great expenditure of labor and fuel.

It will, of course, be admitted that the principles enjoyed at the present time have some merit for they have stood the test of time, but still there is nothing so good that it cannot be improved upon. We will see, as we read on, that marked improvements have been made.

Flame application to continuous tanks has been practiced in a variety of ways in the past thirty years, complicated by requirements that work at cross purposes, leaving the manufacturer content to struggle on, making the best possible use of his furnace design, gradually improving a little here, a little there, and less able than ever as the time rolls on to pursue new methods of combustion that depart radically from the heretofore accepted principles.

Previously, it has been possible to increase melting rates and improve efficiencies only by increasing flame temperatures, thereby accelerating refractory wear to such an extent that a heavily pulled tank now finishes a campaign on the verge of total collapse. Progress made in diffusion combustion during the past year has justified predictions as to the industrial value of the development.

What Is Diffusion Combustion?

The principle of Diffusion Combustion makes possible the following improvements over old methods: an increased melting rate with a substantially lowered flame temperature; refractory wear is localized, reducing routine repairs to the minimum; the melting process is stabilized, insuring consistent quality and uniform results; the melting unit is compact and self-contained.

Before elaborating on these results it will be well to give the reader a detailed understanding of this new process of combustion. In many instances, it has been difficult to establish an understanding of the difference between luminous combustion and diffusion combustion. In forging, for example, luminous combustion cannot produce scale-free forgings, whereas diffusion combustion can heat steel to forging temperatures without the formation of any

scale whatever. The fact that diffusion combustion is luminous tends to confuse the difference in its performance as compared with conventional luminous combustion.

Despite remarkable achievements in its application to industrial heating processes, diffusion combustion is not a "cure all." It cannot be applied to all furnaces. Up to this time, the scope of its application has been limited, but now it is being expanded rapidly. For the present, the field of application will be limited and each job should be given thorough engineering analysis. It is felt that only in this way can logical developments of the new process be realized.

We must bear in mind that diffusion combustion has two different functions—first, increased radiation which effects heat transfer, and second, the control of the convection currents in the glass by the control of heat liberation.

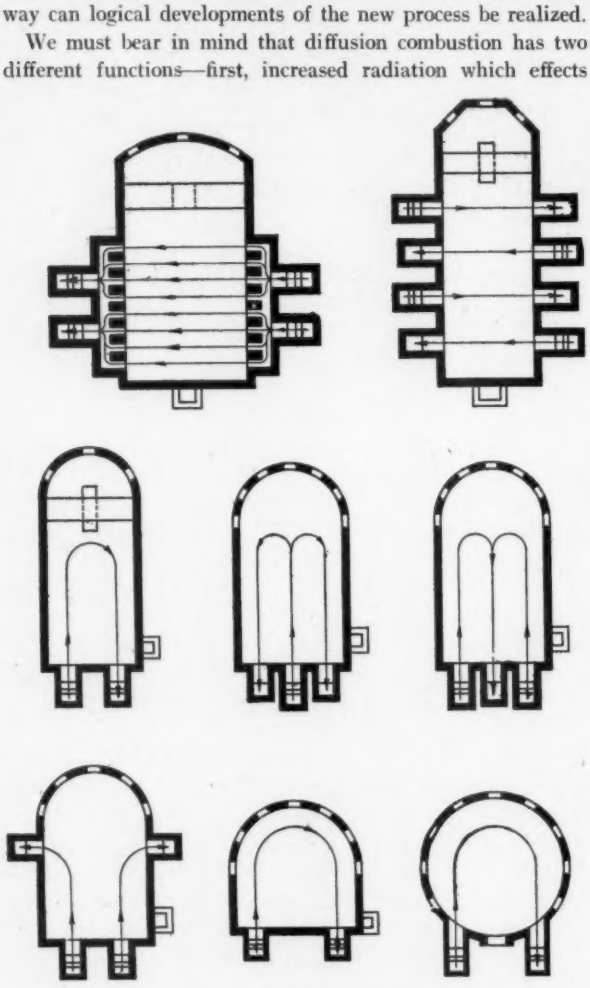


FIG. 1-A

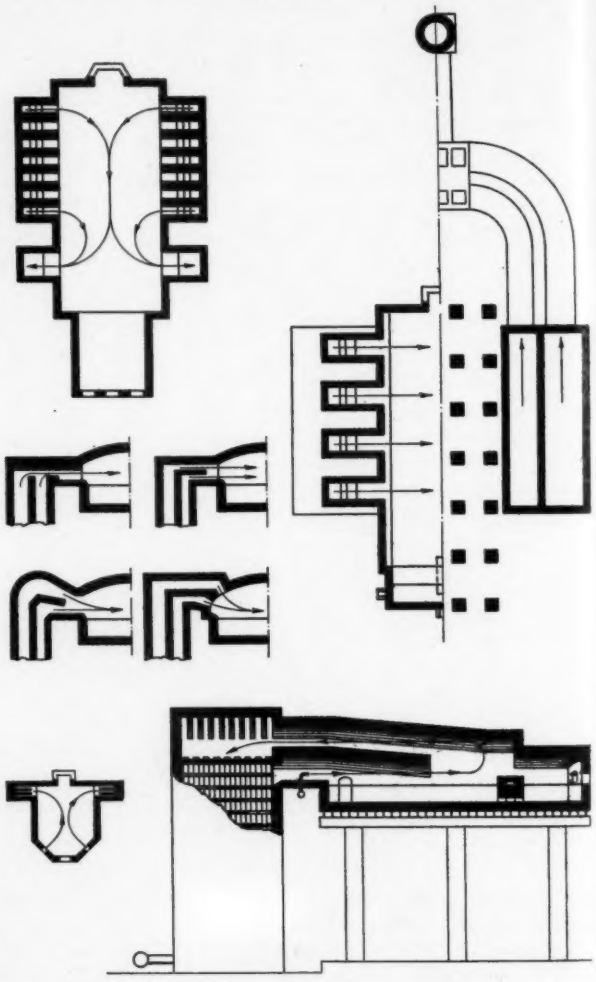


FIG. 1-B

FIG. 1-A AND 1-B ARE VIEWS OF TRADITIONAL MELTING TANKS, SHOWING FLAME TRAVEL, AND SECTIONS OF PORT DESIGNS

It seems best to treat the development separately in its two phases, taking the radiating or heat transfer characteristic first. For simplicity certain frequently asked questions will be stated and answered.

Is it true that luminous type of combustion heats faster than a nonluminous combustion?

The fastest type of commercial heating is nonluminous. There has been completed recently an installation of natural gas on copper smelting reverberatory furnaces in which a nonluminous combustion is utilized. These applications have stepped up the rate of heat transfer with natural gas over that formerly obtained with more luminous types of oil application. The combustion is made to impinge directly onto the bath. Gas and air are mixed in such proportions that the hot zone of this combustion will occur directly on the surface. This impinged type of combustion is nonluminous and is the fastest type of heating by gas which we know.

We should bear in mind that to make a flame luminous we must violate good combustion principles, and if we do not offset these violations by something more than mere luminosity, we have nothing more than we have had for the last 300 years.

If a flame must be made luminous, it should be given every bit of free carbon possible.

Can we say in general that gases at certain temperature will transfer heat at a faster rate if free carbon is present than if the gases are nonluminous?

That is correct. There is a certain amount of radiation from nonluminous gases, but the addition of free carbon will speed up this rate of heat transfer by radiation for any given temperature of those combustion gases.

Does the amount of carbon added vary the luminosity under fixed conditions?

This is not really a correct question for the reason that luminosity is not a quantity but merely an optical observation. If a flame shows color, we say it is luminous.

Luminosity, as discussed, is merely an indication of an unknown amount of free carbon in the combustion. It is impossible to ascertain with the eye the increase in radiation due to the addition of free carbon.

Luminosity cannot be measured in terms of heat. There is an increase in radiation with addition of free carbon; this must be expressed by the term "emissivity." The substance which, at a given temperature, would give off the greatest possible amount of heat by radiation is known as a black body.

Luminosity and Radiation

Luminosity is in part derived from incandescent carbon particles in the flame, but its intensity in terms of light is no accurate index of the concentration of suspended carbon.

In measuring flames on the basis of heat emissivity it is immediately apparent that visible luminosity ceases to have any direct significance, and that the criterion must be the total capacity for radiating energy, visible and otherwise.

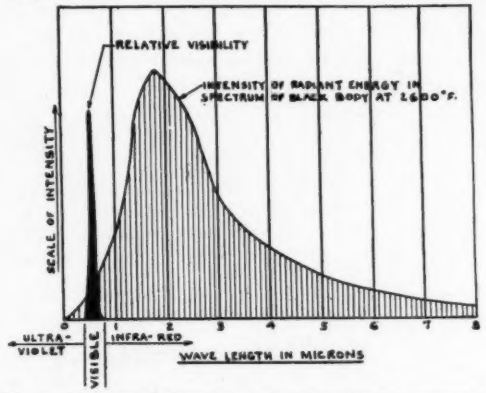


FIG. 2—CHARACTERISTICS OF RADIATION SPECTRUM

As will be shown, a flame having high visible luminosity may be a poor medium for radiant heat transfer.

Radiation is that form of energy which may be transferred through space or vacuum from a heated body to a cooler one. The body thus losing its energy may be termed the radiator, and the one receiving such energy, the absorber. The ideal radiator, as well as the ideal absorber is a "black body" or a body which reflects no radiation.

At elevated temperature, the "black body" ceases to be black to the eye and becomes incandescent. The radiation spectrum of an incandescent solid has an energy distribution somewhat as shown in Fig. 2.

The intensity of radiation is maximum for a certain wave-length and falls off gradually for longer and shorter wave-lengths. As the temperature increases, the wave-length of most intense radiation becomes shorter, and the energy curve is shifted bodily toward the ultra-violet. Likewise the total energy radiated per unit area of heated surface rapidly increases. This accounts for the changes in both color and brightness of objects being heated.

For all temperatures encountered in industrial heating operations, the peak of the energy distribution curve is well in the infra-red region of the spectrum. All visible radiation is confined to a narrow band at the violet end. Thus an extremely good radiator at relatively low temperature may actually have less energy in the visible band than a much poorer radiator at a somewhat higher temperature. The integral of energy in the visible band is thus no index of the integral of the whole curve. It may be stated that "you cannot see heat!"

Emissivity is a term used to express what percentage of black body radiation the particular flame or material in question represents.

Likened to Keyboard

A simple way to establish an understanding of this term is to consider a piano keyboard as representing the different wave lengths represented in the complete range of heat waves. Let us say that the keyboard would have 80 keys. If all of these keys were struck simultaneously, the vibration given off would represent the radiation given off by a true black body. If a chord of 8 notes were to be struck, this would represent a substance having an emissivity of 8 divided by 80, or 0.1. The emissivity of a black body is represented as 1. If this particular chord should have base notes in it, it would be luminous; if there were only treble notes, it would be nonluminous.

How does the heat radiated increase with an increase in the amount of free carbon?

For any given temperature, radiation increase is in direct proportion to the emissivity. Carbon particles are extremely small; certain authorities have determined them as being 0.0003 millimeter in diameter. Such a dimension is less than most of the wave lengths of heat emitted by combustion, so that these particles can be nearly transparent to the heat waves. It has been reckoned that they would absorb only 5.5 per cent of the heat radiated to them.

The heat which a particle can absorb, or its absorptivity, is a function of how much heat it can radiate, or its emissivity. We can consider that a thin sheet of glass will absorb only a slight percentage of the heat from the sun's rays going through it. However, if we put another sheet of glass back of the first and another back of that, and use a sufficient number of sheets, we will be able to absorb the major portion of the sun's rays.

This is somewhat similar to the carbon particles absorbing the heat radiated to them. However, in this case, we have wide spaces between the particles in which no carbon particle would be hit by the heat wave. Furthermore, we have the transparency characteristic which permits the particles to absorb only a small percentage when a ray does strike them. This is one of the fundamental reasons why it is of such great importance to inject a multitudinous number of these free carbon particles to build up a body which will cause the flame to act somewhat approaching a black body, or in other words, to build up its emissivity.

In shooting a rifle bullet at a single row of corn growing in a field and from a point at right angles to the row, it is unlikely that the bullet will hit any one of the corn stalks; it would go through without giving up much of its energy. On the other hand, if the bullet were fired into

two or three square acres of corn, the law of averages would insure hitting a great number of stalks and the bullet would impart most of its energy to the stalks and would not reach the other end of the field. In a crude way this is what happens with the heat wave in a diffusion flame. A number of layers of flames are used, each of which has a corresponding dense bank of free carbon and thereby a high percentage of the energy of combustion is absorbed and transformed into the form of radiant heat.

Sources of Radiant Energy

Stefan and Boltzmann's law states that the rate of heat transfer by radiation is proportional to the difference between the fourth powers of the absolute temperatures of the radiator and the absorber. The transfer of heat by convection, on the other hand, varies only as the temperature difference between the heating gases and the absorber. It is therefore apparent that as temperatures rise, the importance of radiation rapidly increases.

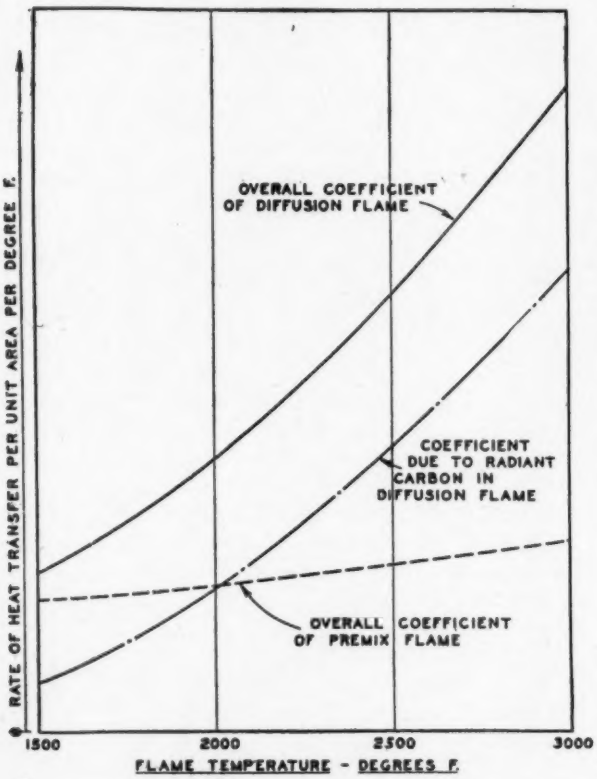

RATE OF HEAT TRANSFER PER UNIT AREA PER DEGREE F.
OVERALL COEFFICIENT OF DIFFUSION FLAME
COEFFICIENT DUE TO RADIANT CARBON IN DIFFUSION FLAME
OVERALL COEFFICIENT OF PREMIX FLAME
1500
2000
2500
3000
FLAME TEMPERATURE - DEGREES F.

FIG. 3—HEAT TRANSFER RATES FROM DIFFUSION COMBUSTION AND PREMIX FLAMES

The refractory walls of a gas-fired furnace absorb some heat from the flame and, if they are sufficiently insulated, radiate heat to the substances within the furnace. With premix combustion the walls are the principal source of radiation. The familiar temperature limitations of refractories, however, make wall radiation a questionable asset in very hot furnaces. If the flame acts as the radiator instead, the walls become merely an agency for inclosing and insulating the combustion chamber.

In Diffusion Combustion the greatest possible time interval has been secured between the cracking of a hydrocarbon molecule and the subsequent oxidation of the resulting carbon particle. This has made possible the generation of flames loaded with a maximum of incandescent solid material. Spectral analysis of the diffusion flame shows its radiation to resemble closely that from a true black body. By utilizing to the fullest extent the radiation potentialities of the continuous energy spectrum, the diffusion flame accomplishes higher heat transfer rates with lower temperature differentials between flame and work.

Characteristics of Diffusion Flames

The black body emissivity coefficient of diffusion flames in practical heat applications ranges between 0.4 and 0.6 and will vary with the rate of gas consumption per square foot of heat-absorbing area. Knowing this coefficient, it is possible to calculate necessary flame temperatures for various heating operations. Fig. 3 shows how rapidly the rate of heat transfer from diffusion flames increases with increasing temperature as compared with premix flames. The two curves for over-all coefficients are based on actual laboratory measurements. The third curve, showing the coefficient due to incandescent carbon alone in the diffusion flame, has been added to emphasize the comparative importance of this agency in the mechanism of heat transfer.

In addition to affording the greatest possible radiation, diffusion combustion has other beneficial features. Because heat is liberated uniformly along the entire flame length, except for a short preheat zone near the burner, it is possible to cover the entire hearth of a furnace with a radiant flame with uniform heating rates at all points. Actual measurements made in a laboratory furnace illustrate the longitudinal distribution of the critical flame characteristics (see Fig. 4). The curve, "heat absorbed by water coolers," was derived by computing the heat transfer per unit of surface area on water-cooled members placed on the hearth of the test furnace at regular intervals.

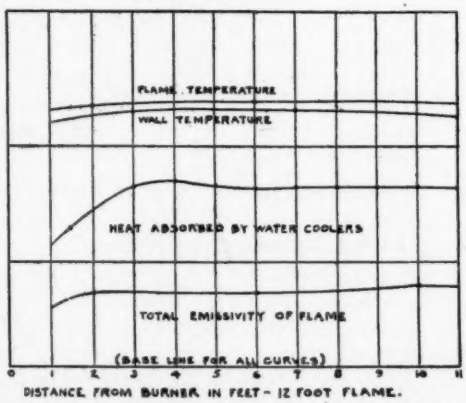

FLAME TEMPERATURE
WALL TEMPERATURE
HEAT ABSORBED BY WATER COOLERS
TOTAL EMISSIVITY OF FLAME
(BASE LINE FOR ALL CURVES)
0 1 2 3 4 5 6 7 8 9 10 11
DISTANCE FROM BURNER IN FEET - 12 FOOT FLAME.

FIG. 4—CHARACTERISTICS OF DIFFUSION COMBUSTION FLAME

Since all elements of the diffusion flame travel in substantially parallel lines and maintain their relative position, a thin blanket of gas or air may be introduced along any boundary of the burner face and carried through the furnace unbroken as a protecting layer to completely eliminate undesirable oxidizing or reducing effects on the heated material.

True diffusion flames up to 32 feet in length have been studied in the laboratory, and with this length there was no indication that any limiting conditions were being approached. Burners have also been designed to obtain complete combustion by this method when burning 360 cubic feet of natural gas per cubic foot of combustion chamber per hour.

Facts Confirmed by Performance

Experimental furnaces have been built in which have been tried out various types of combustion—nonluminous, luminous and diffusion combustion—all in the same setting and this prompts the next question:

Wherein then does the distinction lie between the diffusion combustion and previous methods of luminous combustion?

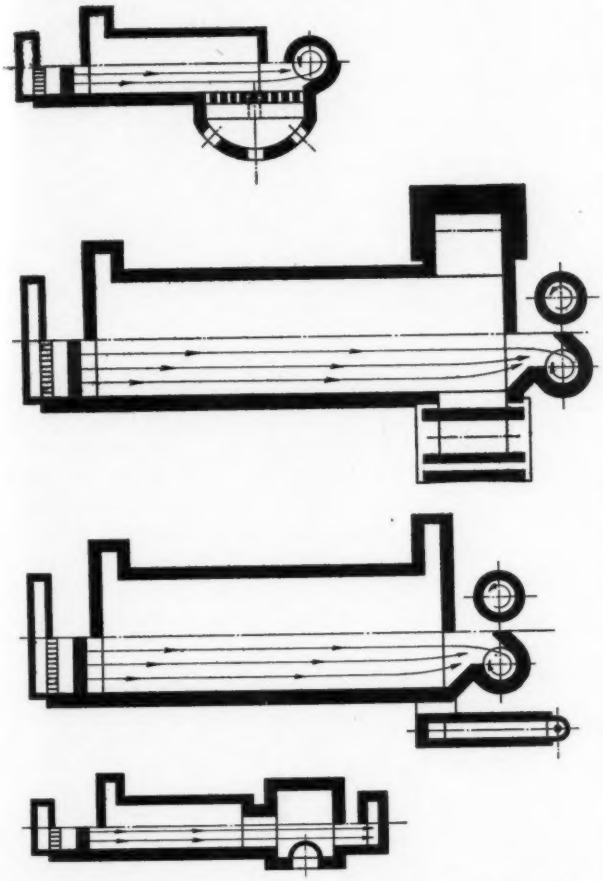


FIG. 5—PLAN VIEWS OF DIFFUSION COMBUSTION FIRED TANKS SHOWING FLAME TRAVEL AND VERSATILE ADAPTATION TO DIFFERENT MANUFACTURE

Three distinctions can be cited:

1. Diffusion combustion holds practically a constant rate of radiation for its designed length of travel, that is, its emissivity is constant. Combustion is at a constant rate and carbon liberation is uniform.

2. It contains the greatest amount of free carbon possible with combustion. A stream line flow of the gas and air strata insures a constant condition and the maintenance of that zone which produces the greatest breakdown of free carbon.

3. It preserves a constant flame temperature for its designed length of travel.

The practical value of these three distinctions will be in the increased rate of heating which diffusion combustion will give over luminous combustion, a lower furnace temperature with correspondingly decreased maintenance costs, a more accurate control over variations which the automatic temperature controls require and a better surface condition on the materials heated, which in turn increases the metallurgical capacity of quality glass. Some economies might also be effected in fuel consumption. It might be added that with the use of the Stein recuperator for pre-heating the air used in diffusion combustion, results are gratifyingly lower in fuel per ton than with checker chambers.

In principle, diffusion combustion utilizes the characteristics of two gases to intermingle or to diffuse due to their molecular activity. It is well known, for example, that if a gas holder were filled in the bottom half with air and the top half with gas that within a short time and without any circulation, the two gases would become completely intermingled due to their molecular activity or diffusivity. This characteristic is utilized in diffusion combustion. Strata of air and gas are made to travel in parallel formation adjacent to each other without turbulence. The molecular activity or the diffusivity of the two gases causes an intermingling of the two, grading from the perfect combustion mixture on down to the strata which are prolific of free carbon breakdown.

Diffusion Combustion as Applied to Glass Melting

Radiant heat energy from diffusion flame combustion serves three distinct functions in the continuous glass melting tank: (1) it raises the batch to the furnace temperature and accomplishes the reactions incidental to melting; (2) it assists the effervescent ingredients of the bath in promoting stirring to secure homogeneity through the medium of convection currents in the bath; and (3) it maintains the molten glass at a high temperature and low viscosity during its progress toward the working end and so facilitates the escape of submerged gases and maintains uniform flow throughout the tank cross-section.

This ideal system of heat application will accomplish the following functions with maximum efficiency and with minimum refractory wear: (1) apply a penetrating and uniform heat to the melting zone; (2) afford controllable temperature gradients throughout the length and width of the tank which, when established, will remain constant; (3) prevent local overheating; and (4) maintain the furnace atmosphere under control.

To allow the maximum of time and space for planing the melted glass, the actual fluxing of the batch must be confined to the least possible area at the charging end of the

"NOW I WONDER WHAT IN THUNDER THE TROUBLE IS." (THE STACK IS SMOKING.)

tank. This requires that surface currents in the glass shall be such as to hold back unmelted materials. Since these currents tend to flow from hotter to colder zones in the bath, the maximum temperature in the tank must be kept well forward of the melting zone to set up surface currents bearing toward the back wall. The remaining convection currents will then flow toward the side walls at the surface and promote mixing without accelerating the movements of surface glass toward the working end.

With such temperature gradients established and maintained, the flow of glass toward the working end is relatively uniform over the tank cross-section. If anything, the lower strata containing the more refined glass will advance more readily. Thus a maximum area is made available for fluxing the bath with the assurance that the refining will be complete.

Diffusion Combustion in the Glass Tank

The application of diffusion combustion to glass melting resulted from a comparison of the characteristic properties of the diffusion flame with the requirements just set forth. Its unique temperature gradient is admirably adapted to the requirements for ideal convection currents when the tank is fired from the charging end (see Fig. 7). The numerous advantages of highly radiant combustion are also realized, and combustion control as a requirement for efficiency is effectively obtained.

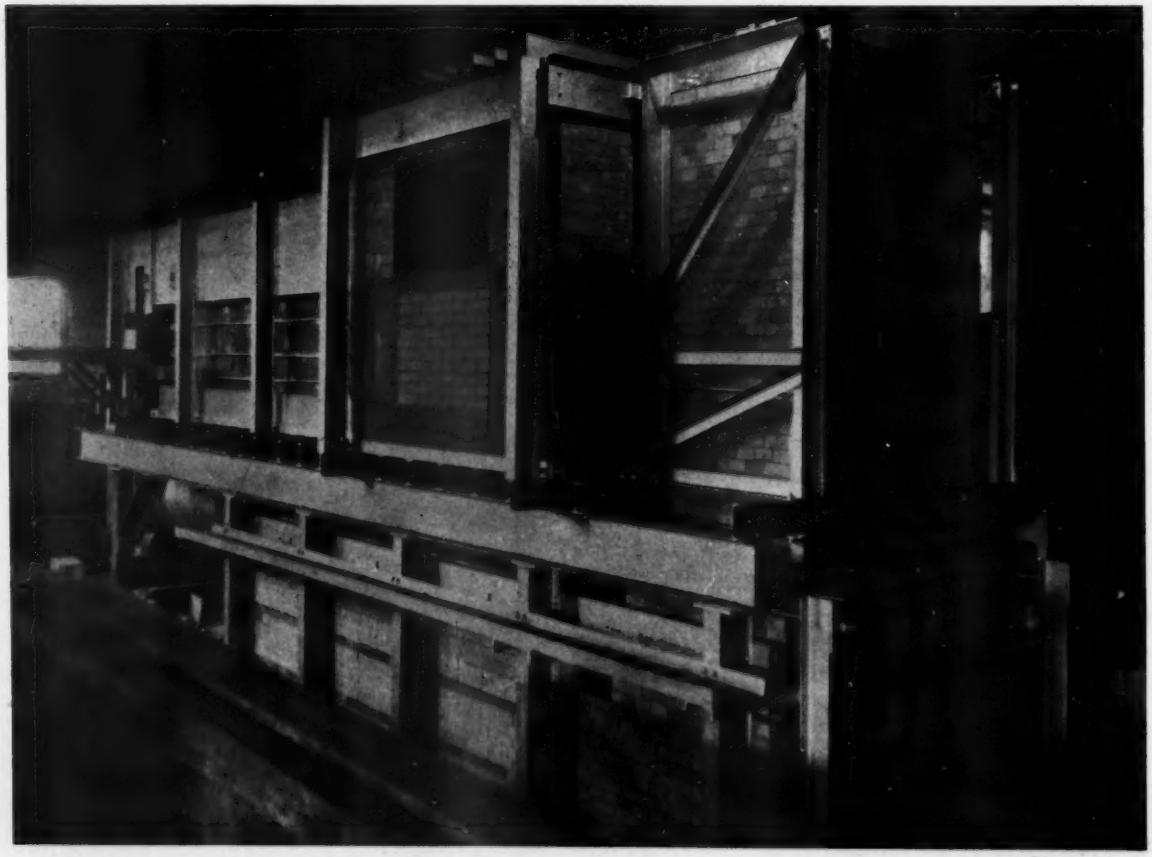
Since the flame fills the combustion chamber completely, every square foot of bath area is effectively utilized for heat transfer. The low temperature differential required for heat transfer reduces the temperatures of refractories and flue gas.

Glass Melting Requirements Met by Diffusion Combustion

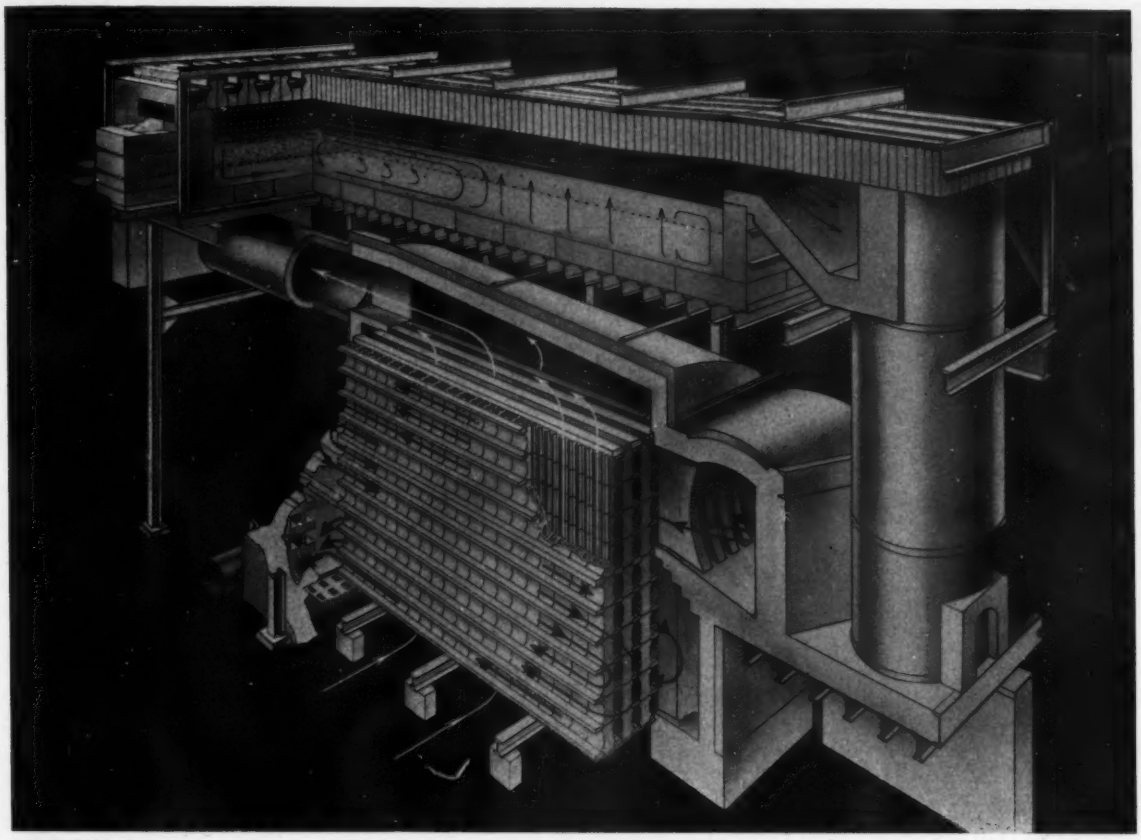
Convection currents within the molten glass are necessary in melting glass batch into quality glass. They are caused and controlled by temperature differences. The glass near the top of the bath and at the center of the furnace becomes hot and expands, suffering a corresponding loss in density. The surrounding glass, being cooler and more dense, forces this hotter portion upward, causing a surface flow radiating from the hot center portion of the tank. Colder glass meanwhile flows from the sides and end walls of the tank, following the bottom, to replace that removed by the surface flow.

Devitrification and Scum Enhanced by Poor Convection

By holding glass sufficiently long at the temperature of the greatest crystallizing tendency, we can produce crystallization. The glass loses its characteristic properties, which are liquidity, uniformity, homogeneity and amorphous condition. This condition is common in improperly shaped continuous tanks where uncontrollable convection currents cause whirlpools and dormancy in corners, defeating the time temperature curve required for a perfect transmutation.



DIFFUSION COMBUSTION GLASS MELTING TANK IN PLANT OF THE LIBBEY GLASS MANUFACTURING COMPANY



SECTIONAL VIEW OF GLASS TANK DESIGNED FOR DIFFUSION COMBUSTION AND SHOWING THE DIFFUSION COMBUSTION FLAMES AND RECUPERATOR

Importance of Controlled Convections

These currents, when controlled by diffusion combustion characteristics, set up an effective means of heat transfer, characteristic of fluids, also enhance refining by speeding up the liberation of seeds, the convection currents bringing them closer to the top surface.

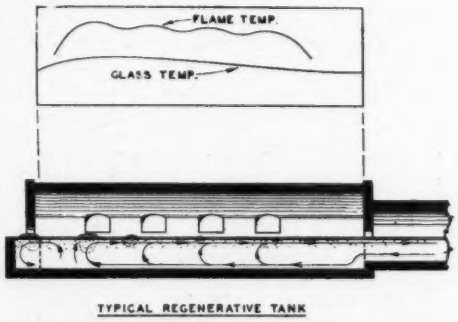


FIG. 6
THIS SECTIONAL DRAWING ILLUSTRATES THE TEMPERATURE GRADIENT, AND THE CONVECTION CURRENTS IN THE GLASS

The present regenerative furnaces require the constant attention of a furnace operator to try and prevent the longitudinal convection currents which can easily be set up in a tank, which cannot readily be detected by visual examinations but which can create rapid movements of unfinished glass into zones where finished glass should exist.

In furnaces of small dimensions, it is often found with large fillings that "islands" of partially melted batch may become carried by flow as far as the bridge wall of the furnace. This, of course, is very dangerous practice.

The continuous tank furnace is probably the worst offender in producing this condition without controlled heat application. If any segregation has taken place in the batch due to uncontrolled convection currents, the tank will do nothing, or next to nothing, to amend it.

If the tank could be fired with bottom heat, or even side heat, a much more vigorous stirring could be obtained, but the limitations of our refractories seem at present to prevent that.

In continuous tanks, the "pull" or metallurgical capacity at which glass is drawn from the working chamber determines the time allowed for the planing process, and this must be gauged by the ability of the heat application to hold to the exact time temperature curve required for the particular batch mixture under treatment.

It has been repeatedly demonstrated that the stirring action of convection currents, most manifest in closed pots, where one end is much hotter than the other, play a useful part in making glass homogeneous during the melting process. In a uniformly heated pot, for example, it would be practically impossible to melt a glass high in lead oxide without great differences in composition between top and bottom glass.

Glass being made up of a number of constituents in

mutual solution, these constituents vary in density and in volatility: and their relative proportions in finished glass must be closely maintained to meet the requirements of quality. Diffusion combustion controlled convection currents assist melting by spreading out the granular mass of batch and subjecting it to the flow of fluxing material. Volatile ingredients are included in batches to generate gas and agitate the bath. If the convection currents flow in the wrong direction, it defeats the metallurgical time requirement. A compromise is frequently effected by adding more flux to avoid a possible reoccurrence. In other words, the barn has been locked after the horse has been stolen.

We are thus dealing with an agency which is admittedly responsible for most of the defects of present continuous tanks, but without which the melting of glass in such tanks would probably be impossible.

It can readily be seen that in the control of convection currents by the control of heat application we have the key to the entire problem of efficiently and thoroughly melting glass in continuous tanks.

Traditional Method of Increasing Metallurgical Capacity

Raising the temperature of the glass to increase the fluidity does have an effect in the release of larger amounts of gas from the batch. However, in many glass batches, it is a somewhat dangerous practice.

Higher temperatures, particularly if long continued in concentrated spots, may burn out decolorizing agents, or in the case of colored glasses may ruin the color. Diffusion combustion, however, proves that tank capacity is not proportional to temperature difference but is affected by flame radiation capacity. In actual operation diffusion combustion has melted glass faster with lower flame temperature than previously thought possible.

It is quite obvious that diffusion combustion is free from hot spots, and is more easily adjusted to the temperatures required and, when once set, the exact temperatures can be maintained.

Summarized Results

In conclusion we find that the diffusion combustion glass melting process has yielded the following advantages, which are the results of actual operation:

1. The recuperative, diffusion combustion melting tank requires only half the floor space, for a given tonnage, that is occupied by a standard regenerative tank.
2. The new process will yield one ton of quality glass per day for each ton glass capacity of the melting chamber.
3. The diffusion flame tank has but one inlet port and one outlet port for any size tank.
4. The diffusion flame flows constantly in one direction.
5. The temperature in the diffusion flame tank remains constant at any given point and gives an easily controlled temperature curve for both lateral and longitudinal sections of the melting area.
6. The diffusion flame covers the entire area of the melting tank for the transfer of heat. The average spot heat application covers only 50 to 65%.
7. Because of its intense radiant heat to each square foot of the bath, with greatly reduced temperature differentials, the metallurgical capacity can be increased over that of any convectional design with nonluminous or the so-called luminous flame. Lower flame and flue gas temperatures from diffusion combustion reduce the deterioration of refractories, and reduce radiation loss.
8. The atmosphere above the melt can be controlled over the entire area, avoiding local hot spots and the extreme oxidizing or reducing conditions characteristic of other flames.
9. The length of flame can be varied at will from one control point, making it easy to confine all combustion to the furnace.
10. The diffusion flame burner unit is so mounted as to be integrally lowered from its operating position for cleaning and inspection, while the tank is at full heat.
11. The diffusion combustion process allows the use of a flat suspended arch, which is free from expansion rod adjustments, and can be insulated with 2½" to 3" of insulation without fear of deterioration.
12. Diffusion combustion process brings to light a glass melting tank design that is applicable to all capacities from 1 ton to 200 tons or larger. The side walls being entirely free from ports and checker chambers, are freely accessible for inspection and afford ample room for the application of air or water coolers as needed. The rear is free from large reversing valves, flues and complicated accessories.
13. Since the diffusion flame fires from the end, and can be made as long as desired, we are able to go to a relatively long and narrow furnace, eliminating dormant corners, etc.
14. The combination of accurate flame control with control of convection currents enables a desired time temperature curve of melting to be established and adhered to.
15. The soft, radiant diffusion flame admirably fits the requirements for melting all glasses which are sensitive to temperature changes from hot spots, resulting from concentrated turbulent flames.

THE BATCH FLOWED FORWARD AND PUT US IN THE RED

Conclusion

The art of melting glass has lagged far behind the spectacular advances made in the mechanical working of the molten metal. In fact, these advances have been made in spite of the many limitations imposed by delivery to the

(*Continued on page* 21)

Egyptian Glass

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IF we consider the great rivals pottery and glass there is one important difference to be noted between the two. It has been natural from the earliest times for peoples in different parts of the globe to work plastic clay into domestic utensils of various kinds. It is difficult to imagine a state so primitive that this art should be entirely unknown. The fact, also, that the raw material of pottery is so widely distributed and so readily accessible makes it certain that its use has come about spontaneously in many places widely separated from each other. The history of races, and their contacts with one another, has often been traced by the shape and decoration of their pots, but it has never been suggested that the making of pottery has originated in one particular place.

Glass, in contrast to pottery, represents a considerable advance from primitive conditions. It is of the type of product that must be discovered, or rather that is slowly evolved as the result of a series of discoveries. It is probable that glass developed from glazes used on pottery, etc. It was thought until a very few years ago that the original home of glass-making was Egypt, but it has now been shown by the investigations of Sir Flinders Petrie that the Egyptians themselves learned the craft from some earlier and external people.

Sir Flinders has stated that the earliest glaze discovered by him was green in color, and was applied to stone beads of the Bedouian age in Egypt, about 12,000 B.C. As early as about 9,000 B.C. green glaze of Egyptian manufacture was also applied to a basis of powdered quartz for making small figures. Of pure glass the oldest known is a molded amulet of deep lapis lazuli color dating from about 7,000 B.C. In the first dynasty, about 5,000 B.C., green opaque glass inlay appeared, followed in the ninth, 3,800 B.C., by striped black and white glass amulets, and about 1,570 B.C. by translucent blue beads. These glasses can all be regarded as having been imported from Assyria.

Glass was not actually manufactured in Egypt before about 1,500 B.C. At that period we find sculptural records with representations of Syrian workmen being brought into Egypt, carrying the vases of glass or metal they had made. At that time the Syrians were far in advance of the Egyptians in art and industry, and glass has been found in the Euphrates region which can definitely be dated back to 2,500 B.C. We know, that is, that the Syrians were making glass at least a thousand years before the Egyptians, and there is little difficulty in attributing the still earlier glassware to them.

As regards Egypt itself the earliest glass is represented by fragments only, mainly for inlay, and dating from many centuries apart. The few pieces discovered belonging to the First Dynasty were followed by nothing that could be dated earlier than 3,500 B.C., an interval of two thousand years. It is the view of Sir Flinders Petrie that this first known glass was probably produced somewhere in the northern region of Mesopotamia, or possibly still farther north in the Caucasus, and that these may well have been centers of glass-making for a long time prior to the production of glass in Egypt. He points out that it is significant that only fifty years or so elapsed between a time when glass was a comparatively rare commodity in Egypt and one when it was possibly the commonest of all. There seemed to rise quite suddenly in Egypt factories producing enormous quantities of glass, so that glass vases and beads sprang quickly into everyday use.

In just the same way that the Egyptians were led from their trading in glassware to introduce the manufacture of it on their own soil, so in time knowledge of the craft was passed on to Rome, Byzantium and Venice, then slowly across Europe to England, and lastly the big step across the Atlantic to America, where the application of mechanical methods of production in the present century have given

(*Continued on page 23*)

Diffusion Combustion

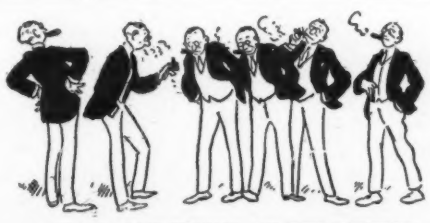
(*Continued from page 20*)

machine of glass lacking the homogeneous qualities most desirable.

The melting process involves many complex reactions, both physical and chemical, which are directly affected by the method of heat application. Only through a proper understanding of the fundamentals of heat liberation can the conditions inherent to present methods be improved.

The development of diffusion combustion and its application to the melting tank places within the control of the operator a mechanism for liberating heat to the batch at the desired rate, amount and intensity. When these conditions are once determined and set, they remain constant, but can be altered at the will of the operator whenever desired. This reflects itself in a control of melting and refining operations heretofore unattainable, with the result that maximum constant production of the highest grade glass can be maintained at the best overall cost.

Practical equipment, incorporating proven engineering constructions for continued uninterrupted operations, has been developed, tested under severe demands of production, and is now available for the interpretation of this process to the glass industry.



A HEAVY CONFERENCE ON THE SUBJECT OF GOLF

Glass Industry

ESTABLISHED 1920

The First Trade Journal Devoted Primarily to Glass Technology, Engineering, Raw Materials and Glass Factory Equipment and Operation

PUBLISHED MONTHLY

Copyright, 1933, by

GLASS INDUSTRY PUBLISHING COMPANY, INC.

2 Duane Street, New York

Telephone BEekman 3—0474 Cable Address Glasdustry

G. W. Cooper, Managing Editor

Subscription Price..United States $2.00 a Year; Foreign $3.00
Single Copy .....25 Cents

Vol. 14 FEBRUARY, 1933 No. 2

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Reference to the contents of earlier issues of THE GLASS INDUSTRY can be found in THE INDUSTRIAL ARTS INDEX in many Public and Technical Libraries.

Diffusion Combustion

The application of Diffusion Combustion to glass melting tanks, discussed at length in this issue, has long been a subject of investigation, careful study and extended experimentation by the men responsible for the development of the process to the point where they feel justified in announcing that Diffusion Combustion for glass tanks has now become a subject for serious practical consideration by the glass manufacturing industry. In this issue Diffusion Combustion methods are compared with the glass melting methods now in general use and their differences described and summarized.

A Glass Technologist in the South Seas

Mr. J. W. Cruikshank was in Los Angeles part of January, and the following excepts from a letter to Frank Preston may be of interest to many who knew Mr. Cruikshank in the old days in Pittsburgh.

"I left Tahiti on a trip which was orginally planned for three weeks, but developed into seven. We visited Manga Reva in the Gambia Islands, then Ravavai and Tubuai in the Austral. Group. It was very interesting and well worth while. The people and modes of living are decidedly primitive, as these islands are not visited except by trading schooners, and that only at intervals of three to six months.

"The people have no money in Manga Reva, and no means of getting any, as the only article of commerce, copra, is down in price to the vanishing point. They have few wants, however, to satisfy, and live on the natural products of the islands, fish, breadfruit, bananas, sweet potatoes, manioc roots, and so on. You don't hear anything about depression or technocracy, as the people are satisfied with what they have in the way of food and shelter.

"They even prefer the most primitive form of living, and while many of them have a good frame house, they will rather eat in the bamboo and palm-thatched kitchen, squat on the floor, and eat their food off banana leaves with their fingers, the main house, with little furniture, being used to sleep in.

"The woman I boarded with (they gave me a table, table cloth, etc., as I was a 'popaa' or white man), Kiana, told me her mother objected to her squatting and eating like a native. But then Sophie, the mother, runs a rooming house in Papeete (Tahiti), and is the daughter of a Chilian woman with a Dane for a father. They first lived in Easter Island, and then Manga Reva. Sophie married a Swede of the name of Carlson. The daughter Kiana is married to a fine young native of Manga Reva, who has land there.

"I was three weeks in the Gambia Islands, and went with Kiana and her husband to Tera Vai, an island of the group with a population of 30 people. In these islands there is evidence of great activity on the part of the Catholics. There is an enormous church at Rikitea, Manga Reva, other churches on the same island, and a church on three of the other small islands. The priest Laval also built a convent, monastery, king's palace, and other houses of stone and coral block, all of which are in ruins in less than a hundred years, about 70 I think. The population was then about 6,000; now it is about 600.

"There is a rather interesting book, 'Manga Reva,' by Eskridge, which gives this story. And there is one white man living at Manga Reva who comes in the book, and is quite an interesting character. Originally on a ranch in Wyoming, he now has gone completely native; but is still awfully glad to see white people.

"I cannot say I like these United States much after the life in the South Seas, where one is free from evening editions of the papers, radio, and rush, and all the curses of civilization."

Egyptian Glass

(*Continued from page 21*)

glass a new significance to civilization. Each stage has been marked by greater knowledge and extended use of the material. None of the discoveries about the nature of glass have been lost, each nation to learn the art having begun at the point reached by the last. No doubt such a history has many counterparts in the case of other commodities.

When thinking of Egyptian glass it is necessary that we should bear in mind that our conception of glass at the present day is one that was entirely unknown to the ancient world. One of the first aims of the early Egyptian glass-makers was to reproduce precious stones in a cheaper form. They were thus greatly concerned with the problem of obtaining exact shades of color. All the early glass discovered in Egypt is colored, and is never transparent.

The imitation of precious stones in Egypt did not call for glass in a liquid form. What was used was a glass paste that could be molded in the plastic state, in the same way that glass tiles are made today. The early Egyptians never reached the extra 500° or so of temperature needed for glass to become liquid, and accordingly they had no blown glass until the Christian era.

This early glass was, then, non-transparent, always colored, and never sufficiently liquid to be blown. Another noticeable point is that the objects made from it were always small in size, jewelry, beads, little strips of inlay, etc. Even when at a later period more ambitious objects came to be made, such as figure subjects and vases, they were for long on a diminutive scale. This characteristic no doubt resulted mainly from the limitations of glass paste as a material, when compared with glass that could be blown.

From a very early period Egyptian glass was remarkable for its vivid coloring. By far the most important source of these colors was copper, which was used for blues, greens and reds. So great was the predominance of copper that a French writer has even suggested that the making of glass was originally an offshoot of the metallurgy of copper, and that the industry may therefore be specially connected with the copper age. The blues obtained from copper ranged from a rich blue-black in imitation of the *lapis lazuli*, to pale greenish blue shades copying the turquoise or green felspar.

In the case of their reds the Egyptians aimed at the color of the opaque quartz jasper, and in some specimens copper is present to the extent of 15 to 20 per cent. There is always some tin also to be found in these reds, which leads Dillon to suggest that the color was prepared directly from bronze. The use of these copper reds was confined to inlay work, the reason for this being that, if the glass had been subjected to the shaping and reheating which takes place in the making of say a vase, the color would have been lost through oxidization.

A cobalt blue has been found in rare instances from 1,500 B.C. onwards. Manganese purple was known from very early times, and has been found in the glazes of the First Dynasty. A pale yellow, sometimes deepening to a mustard shade, was also a popular color with the Egyptians. It was said to have been obtained by the use of a combination of orchre, a native earth containing clay and hydrated oxide of iron, with an oxide of antimony. We know that the Egyptians were acquainted with the last named metal from the fact that their women folk used it from an early date to darken the outline of their eyes. Antimony had a wide range, for it has also been traced in the glaze of Assyrian bricks and in the yellow enamel of mediaeval Saracenic glass. It should be noted that antimony itself does not give a yellow color, but only an opal one. Its use would probably be to provide a good background for the yellow.

What seems to me perhaps the most remarkable use the Egyptians made of glass was in connection with figure subjects. About 1,200 B.C. they began to press glass in molds. Two results of the introduction of this new process gradually made themselves evident. On the one hand the interest in color became less, and on the other patterns became increasingly composite. Colors became steadily worse for some few centuries, until about the 7th century B.C., in fact. But the building up of patterns from tiny glass rods is what appears to me so very striking. So expert did the Egyptians become in this art that representations of dress for figure subjects were executed in colored glass down to the most minute detail. The patterns were inlaid in mosaic fashion, and so complex was their nature that sometimes the dress on a figure would consist of as many as 100 to 150 squares of colored glass joined together, the glass rods forming the design being drawn out to a diameter of one thousandth of an inch.

The making of the rods used in inlay work was probably derived from the earlier use in connection with beads. In this case the glass rods were drawn out into canes and then coiled round copper wire for re-heating into beads. Thus the Egyptians already had a considerable command over their material in the form of small diameter rods, and the extension of its use to inlay and mosaic work was natural. In the latter advantage is taken of the fact that pieces of glass adhere to one another when softened by heat. After the mosaic had been formed of the little rods of glass it was heated to a plastic condition, and thus fused into a single whole. Edward Dillon states that in the preparation of large slabs for inlay different colored glass pastes were pressed into hollows in a soft condition, and the whole plaque finally reheated to form a homogeneous mass. In these processes we are reminded of the later *millefiori* glass of the Romans.

There was one very interesting use for glass in Egypt which we might have expected to have been common at the present day, that is for the making of standard weights for gold coins. The Egyptian glass-makers molded these glass weights from 350 A.D. onwards. The accuracy of them became so great that we find three belonging to about the year 780 A.D. which agree to within a 200th of a grain, and that although they have already had a life of over eleven centuries. Glass weights became of much importance and usefulness. They ranged from the smallest weights up to over two pounds, and were made both in white glass and various colors. They were embossed with stamps, usually that of the Governor by whom they were ordered, together with the mark of the maker. From the latter marks it has sometimes been possible to trace a family of glass-makers for as long as six generations without a break. Glass weights of normal size came into increasing use until about the 9th century, after which the smaller and more minute weights continued

popular until about the year 1250 A.D., since which date their manufacture seems to have gone out entirely. This appears a matter for regret in that the material has great permanence, as proved by the length of life mentioned a little earlier, and that nothing can very well be taken away from a glass weight without it being visible.

Among the Egyptian glasses some of their small vases are specially attractive. It is said that some of them can be definitely attributed to as early as the Eighteenth Dynasty, about the 16th or 15th centuries B.C. The method of making was described by Sir Flinders Petrie in a report he published of his excavations at Tell-el-Amarna in 1894. He states that "A metal rod, of the size of the intended interior of the neck, and rather conical, was coated at the end with a ball of sand held together by cloth and string. This was covered with glass, probably by winding a thread of glass round it, as large beads of this age are thus made. The vase could then be reheated as often as needed for working by holding it in a furnace, the metal rod forming a handle, and the sand inside the vase preventing its collapse. Threads of colored glass would then be wound round it and incorporated by rolling; the wavy pattern was produced by dragging the surface in different directions, the foot being pressed into shape by pincers, the brim was formed, and the handles were put on. Lastly, on cooling, the metal rod would contract and come loose from the neck, and after it was withdrawn the sand could be rubbed out from the body of the vase."

The wavy decoration mentioned is of two types. In the first, which is the earlier kind, the design consists of a series of crescent-shaped curves, and in the second something of the effect of palm leaves is obtained by means of a double drag. These little vases often attain quite a high degree of artistic merit.

Among other articles of later Egyptian glass should be noticed the small decorated flasks for cosmetics, which show how little customs change with the passing of the centuries, and representations of the scarabaeus or dung-beetle, which was venerated by the Egyptians during its life and often embalmed after death. Several mystical ideas were associated with the scarabaeus and four distinct species have been recognized sculptured on the Egyptian monuments. The scarab gems in glass, formed to represent this sacred beetle, were carried by the Egyptians as personal charms, bringing the owner good fortune and preserving him from danger.

In conclusion it is perhaps of interest to observe that the Romans, who unlike the Greeks made considerable use of glass, became acquainted with the craft through their trading contact with Egypt. It would seem that the first glassmakers to settle on Roman territory did not go to the Imperial City itself, but established their furnaces in Gaul. The towns near this part of the Mediterranean coast were very cosmopolitan in character, and the Eastern glassmakers would no doubt feel very much at home amongst the dense medley of races.

Annual Meeting of Glass Division

American Ceramic Society

The general program of the annual meeting of the American Ceramic Society to be held February 12 to 17, at the William Penn Hotel, Pittsburgh, Pa., was given in the January issue; the detailed Glass Division program appears below. E. Ward Tillotson is Chairman of Division, J. H. Waggoner, Secretary, and H. H. Blau in charge of papers and program.

Glass Division Program

Monday, February 13, 1933

Blue Room

2:00 P.M.

1. Effect of Heat Treatment on Expansivity of Glass

By J. B. Saunders and A. Q. Tool, *Bureau of Standards,* Washington, D. C.

In a progress report presented at the Toronto meeting of the American Ceramic Society (1930) it was stated that preliminary results showed that the expansivity of some glasses was measurably affected by heat treatments in the annealing range; and that the change amounted to about 6% in the case of one sample of the high silica glasses when the treating temperatures differed approximately 100°C. A continuation of this investigation shows that the average expansivity of this glass between 20° and 200°C decreases steadily as the temperature employed in annealing is reduced from 650° to 450°C; and that the total change amounts to about 10%. Changes of this magnitude have presumably a theoretical rather than practical interest. To obtain suitable results in the expansivity tests, it was found advisable to use the interferometric method and small ring specimens between interferometer plates of the same glass.

2. Some Observations on the Relations between Density, Index of Refraction and Dispersion, and on the Thermal Expansion of Some Soda-Lime-Silica Glasses

By A. N. Finn, *Bureau of Standard,* Washington, D. C.

Data have been obtained indicating linear relations between specific volume, refractivity, and dispersion (in the visible range) of some soda-lime-silica glasses and also for some potash-silica glasses. From other experimental data graphs have been prepared showing the relation between the composition of these glasses and the critical temperatures, initial softening temperatures and the expansions to these temperatures.

3. Some Observations on the Release of Strain in Glass

By James Bailey and Donald Sharp, Hamburg, N. Y.

Further work with the apparatus described by the authors previously (*Jour. Amer. Ceram. Soc.,* 14 [11], 811-19 (1931)) has shown that duplication of results is obtained only when the previous thermal history of the samples is the same. The release of strain is thus dependent not only on temperature, time, and certain constants for the glass, but may also depend on the amount of strain previously removed and the time which elapsed between successive applications of the stress. It is indicated that rate of release of strain is not proportional to the square of the strain in all cases but may vary as a different power than this at different temperatures.

4. Gases in Glass

By R. H. Dalton, *Corning Glass Works,* Corning, N. Y.

An apparatus is described for extracting the gas from glass at glass-furnace temperature and determining its composition. Results are given for glasses of various compositions and various melting histories. All ordinary glasses were found to contain appreciable quantities of dissolved (or chemically combined) gas, the amount varying from a few hundredths to a few tenths per cent. Water is frequently the most abundant gas, the content being highest in borosilicate glasses. Carbon dioxide is also usually present, the amount depending on the basicity of the glass. All oxidized glasses contain some oxygen. Glasses containing arsenic give off a comparatively large volume of oxygen. The effect of this oxygen on fining is discussed. It has been found that remelting a glass has

little effect on the gas content. The gas content is greatly influenced by the size of the melt, being the lowest in small experimental melts.

Tuesday Forenoon, February 14

9:30 A.M.

5. Selenium Glass, I. Silica-Soda-Zinc Oxide Series

By Maurice H. Bigelow with Alexander Silverman, *University of Pittsburgh*, Pittsburgh, Pa.

This paper covers a study of the silica-soda-zinc oxide glasses for the purpose of selecting one which remains perfectly clear as a foundation glass for the production of colored glasses. The 4:1:1 glass is then treated in various ways with selenium and cadmium sulfide to study the color production, flashing temperature, etc. The glasses produced are examined spectroscopically and X-ray spectrograms produced to determine the cause of the color. Color-producing factors such as arsenic trioxide, antimony trioxide, carbon, cadmium sulfide, and selenium are considered alone and in various mixtures of these components.

6. Color Changes in Flint Glass

By A. K. Lyle, *Hazel-Atlas Glass Co.*, Washington, Pa., and Donald Sharp, Hamburg, N. Y.

Observations are included concerning rather interesting phenomena of color changes of glasses containing manganese when exposed to sunlight, variations in the color of selenium-decolorized glasses with heat treatment, etc.

7. Spectrometric Analyses of Colors in Glass

By Frederick Brackett, *Bureau of Radiation and Organisms, Smithsonian Institute*, Washington, D. C.

8. The Electrical Behavior of Glass at Room Temperature

By E. M. Guyer, *Corning Glass Works*, Corning, N. Y.

New instruments and equipment are described for the measurement of electrical conductivity of glass at room temperatures. The accuracy of the method is discussed and certain precautions are specified for this type of measurement. A short review is given of the results of measurements with such equipment on a series of glasses at Corning. In particular, experiments are described on the effect of (1) chilling, (2) prolonged heat treatment which produced an actual separation of phases, (3) mechanical strains, (4) superposed radio-frequency currents on the conductivity of the glass at room temperature. In conclusion, it is pointed out that the results of these measurements indicate that the electrical behavior of glass at room temperature is of importance.

9. The Release of Strain in Glass at Low Temperature

By H. R. Lillie, *Corning Glass Works*, Corning, N. Y., and George W. Morey, *Geophysical Laboratory*, Washington, D. C.

Tuesday, 12:00 Noon

Luncheon of Glass Division

Speaker: Francis C. Flint

The Plans for the Symposium on Glass

Tuesday Afternoon, February 14

Blue Room

2:00 P.M.

10. Low Temperature Glass Viscosities Determined from Fiber Elongation

By H. R. Lillie, *Corning Glass Works*, Corning, N. Y.

New viscosity data are given for lime glass LI (*Jour. Amer. Ceram. Soc.*, 14 [7] 502-511 (1931)), in the range of temperatures between its so-called strain point and softening point. Constant temperatures are employed while the whole sample is subjected to a uniform temperature condition. In this way more accurate viscosity values can be computed while the effects of load and time upon rate of elongation can also be observed. The change of viscosity with time at constant temperature is noted and measured.

11. The System of CaO-FeO-SiO_2

By N. L. Bowen and J. F. Schairer, *Geophysical Laboratory*, Washington, D. C.

12. The System, Na_2O-Al_2O_3-SiO_2

By J. F. Schairer, *Geophysical Laboratory*, Washington, D. C.

13. Metal Line Attack in Glass Melting

By Donald W. Ross, *Findlay Clay Products Co.*, Washington, Pa.

14. Report of Committees

(A) Report of Committee on Research
By George W. Morey, *Geophysical Laboratory*, Washington, D. C.

(B) Report of Committee on Standards
Sub-Committee on Tests
By W. C. Taylor, Chairman, *Corning Glass Works*, Corning, N. Y.

(C) Report of Committee on Standards
Sub-Committee on Products
By James Bailey, Chairman, Hamburg, N. Y.

15. The Connection between Conductivity and Viscosity in Glass Melts

By J. T. Littleton, *Corning Glass Works*, Corning, N. Y., K. Lark-Horovitz, and C. L. Babcock, *Purdue Univ.*, Lafayette, Ind.

The electrical conductivity from the strain point to 1400°C has been measured for a lime glass, a lead glass, a lead borosilicate, and a borosilicate glass. The relation between electrical resistance and viscosity for these glasses is discussed.

16. A Method for the Precise Measurement of Birefringence, Especially in Stained Glass

By R. W. Goranson and L. H. Adams, *Geophysical Laboratory*, Washington, D. C.

Wednesday Forenoon, February 15

Blue Room

9:30 A.M.

17. Glass as a Structural and Stress Resisting Material

By Frank W. Preston, Butler, Pa.

A collection of notes on the stresses set up in glassware of various sorts by various forces and treatments, with some observations on how the stresses act to produce failure.

18. A Test on Chemical Resistance of Glass Containers

By F. C. Flint and A. K. Lyle, *Hazel-Atlas Glass Co.*, Washington, Pa.

Suggestions are considered for specifications for use between the customer and the manufacturer of glass containers.

19. Recent Progress in the Cooperative Studies of Illuminating Glasses

By A. B. Oday, *General Electric Co.*, Cleveland, Ohio, and H. H. Blau, *Macbeth-Evans Glass Co.*, Charleroi, Pa.

This paper is a Progress Report of the Joint Committee on Illuminating Glasses of the Illuminating Engineering Society, the Illuminating Glassware Guild, and the Glass Division of the American Ceramic Society. The basis for cooperation between user and producer of illuminating glasses is described together with ideas for classifications, definitions, and proposed methods of testing.

20. Notes on the Classification of Diffusing Glasses

By J. C. Hostetter, *Corning Glass Works*, Corning, N. Y.

21. The Calculation of Limiting Sizes of Flat Glass

By Robert Miller, *Pittsburgh Plate Glass Co.*, Pittsburgh, Pa., and Walter Sturrock, *General Electric Co.*, Cleveland, Ohio.

This paper is based on investigations made for calculating the proper sizes of plate glass for use in various installations and is extended to cover the use of sheet glasses for miscellaneous purposes.

Wednesday, 12:00 Noon

Luncheon of Glass Division

Moving pictures of the Woodmont Meeting of the Glass Division through the courtesy of Paul Geer of the Amsler-Morton Company.

Current Prices of Glass-Making Materials

January 23, 1933

Quotations furnished by various producers, manufacturers and dealers.

Acid		Carlots	Less Carlots
Citric (dom.)	lb.	..	.29
Hydrochloric (HCl) 20° tanks, per 100 lb		..	1.10
Hydrofluoric (HF) 60% (lead carboy)	lb	..	.13½
52% and 48%	lb	10	10-.11½
Nitric (HNO_3) 38° carboy ext. Per 100 lb		5.50	..
Sulphuric (H_2SO_4) 66° tank cars	tor	15.50	..
Tartaric	lb	..	.20
Alcohol, denatured	gal	..	..
Aluminum hydrate ($Al(OH)_3$)	lb	.04½-.05	05½-.06
Aluminum oxide (Al_2O_3)	lb	..	.07
Ammonium bifluoride (NH_4) FHF	lb	..	.15½
Ammonia water (NH_4OH) 26° drums	lb		
Antimony, metallic (Sb)	lb	.02½	.02¾
Antimony oxide (Sb_2O_3)	lb	..	.09⅝
Antimony sulphide (Sb_2S_3)	lb	..	.08½
Arsenic trioxide (As_2O_3) (dense white), 99%	lb	.. .04	.14 04½
Barium carbonate ($BaCO_3$), Crude, (Witherite) 90%, 99% through 200 mesh	ton	47.00	..
90% through 100 mesh	ton	44.00	..
Barium hydrate ($Ba(OH)_2$)	lb	..	05¼
Barium mixture, glassmaker's, f.o.b. St. Louis	ton	25.00	..
Barium nitrate ($Ba(NO_3)_2$)	lb	..	.07¼
Barium selenite ($BaSeO_3$)	lb	..	..
Barium sulphate, in bags	ton	19.00	24.00
Barium sulphate, glassmaker's, carlots, bulk, f.o.b. shipping point,	ton	15.00-16.00	18.00
Bone ash	cariots, lb.	.06	.06
Borax ($Na_2B_4O_7 10H_2O$)	lb	..	..
Granulated	In bags, lb.	.02	.02¼-.02½
Powdered	In bags, lb.	.02¼	.02½-.02¾
Boric acid (H_3BO_3)	In bags, lb.	.04¼	.04½-.04¾
Cadmium sulphide (CdS)—			
Red	lb	..	.60-.75
Orange	lb	..	.55-.65
Yellow	lb	..	1.30-1.50
Chromium oxide (Cr_2O_3)	lb	.18½	.19
Cobalt oxide (Co_3O_4)			
In bbls.	lb	..	1.15-1.25
In 10 lb. tins	lb	.	1.35
Copper oxide			
Red (Cu_2O)	lb	..	.25
Black (CuO)	lb	..	.17-.19
Black prepared	lb	..	.22
Cryolite ($Na_3Al F_6$) Natural Greenland Kryolith)	lb	09	.09¼
Synthetic (Artificial)	lb		.09½
Epsom salts ($MgSO_4$) (imported) Per 100 lb		..	1.15-1.20
Feldspar—			
100 mesh	ton	11.50-17.50	12.00-18.00
80 mesh	ton	11.00-11.50	13.00
40 mesh	ton	10.75-11.00	12.00
20 mesh	ton	9.50-11.00	..
Fluorspar (CaF_2) domestic, ground, 96-98% (max SiO_2, 2½%)			
Bulk, carloads, f.o.b. mines	tor	30.00	..
In bags or barrels	tor	34.00	39.00
Imported	tor	30.00-31.00	33.00-37.00
Formaldehyde	lb	..	.07
Graphite (C)	lb	..	04-.07
Iron oxide—			
Red (Fe_2O_3)	lb	..	.0425
Black (FeO)	lb	.04½	..
Kaolin (f.o.b. mine)	ton	8.00-9.00	..
English, lump, f.o.b. New York	ton	14.50-25.00	24.50-30.00

Kryolith (see Cryolite)		Carlots	Less Carlots
Lead chromate ($PbCrO_4$)	lb.	..	.30
Lead oxide (Pb_3O_4) (red lead)	lb	.055	.06½
Litharge (PbO)	lb	.045	.05½
Lime—			
Hydrated ($Ca(OH)_2$) (in paper sacks)	ton	5.50	..
Burnt (CaO) ground, in bulk	ton	5.00	..
Burnt, ground, in paper sacks	ton	7.00	..
Burnt, ground, in 280 lb. bbls.	Per bbl	2.15	..
Limestone ($CaCO_3$)		1.50-2.50	..
Magnesia (MgO)—			
Calcined, heavy (in bbls.)	lb	.06	.07
light (in bbls.)	lb	..	.23
extra light (in bbls.)	lb	..	.27
Magnesium carbonate ($MgCO_3$)	lb	.06	.10
Manganese 85% (MnO_2)	lb	.03	.03
Nickel oxide (Ni_2O_3), black— for nickel content	lb	..	.35
Nickel monoxide (NiO), green— for nickel content	lb	..	.35
Plaster of Paris, bags	ton	21.00	23.00-29.00
Potassium bichromate ($K_2Cr_2O_7$)—			
Crystals	lb	.09	.09¼
Ground	lb	11	.12
Potassium carbonate—94-96%	lb.	.0555	.0555
Calcined (K_2CO_3) 96-98%	lb	.06¼	.07
Hydrated 80-85%	lb	.05¾	.06¼
Potassium chromate (K_2CrO_4)	lb.	..	.25
Potassium hydrate (KOH) (caustic potash)	lb	07¼	.08
Potassium nitrate (KNO_3) (gran.)	lb	..	.06-.06¼
Potassium permanganate ($KMnO_4$)	lb	.16½	.17
Powdered blue	lb	..	1.35
Rochelle salts, bbls.	lb	..	.13½
Rouge	lb	..	..
Rutile (TiO_2) powdered, 95%	lb	.15-.20	.20-.25
Salt cake, glassmakers (Na_2SO_4)	ton	22.00	..
Selenium (Se)	lb	..	1.70
Silver nitrate ($AgNO_3$) (100 oz.) per oz		..	.19¼
Soda ash (Na_2CO_3) dense, 58%—			
Bulk, on contract	Flat per 100 lb	1.05	..
In barrels	Per 100 lb	1.38	1.90-2.13
In bags	Per 100 lb	1.17½	1.72½-1.92½
Spot orders.. .025 per 100 lbs. higher		..	..
Sodium bichromate ($Na_2Cr_2O_7$)	lb	07	07½
Sodium hydrate (NaOH) (caustic soda) Solid	Per 100 lt	2.50	..
Sodium nitrate ($NaNO_3$)—			
Refined (gran.) in bbls.	lb	..	3.62
95 per cent	Per 100 lb	1.195-1.295	1.145-1.345
Sodium selenite (Na_2SeO_3)	lb	..	2.00
Sodium fluosilicate (Na_2SiF_6)	lb	.05½	.06
Sodium uranate (Na_2UO_4) Yellow or Orange	lb	..	1.50-1.55
Sulphur (S)—			
Flowers, in bbls.	Per 100 lb	3.45	3.80-4.00
Flowers, in bags	Per 100 lb	3.10	3.45-3.65
Flour, heavy in bbls.	Per 100 lb	2.85	3.20-3.40
Tin chloride ($SnCl_2$) (crystals)	lb	.37½	.39
Tin oxide (SnO_2) in bbls.	lb	.28	.29½
Uranium oxide (UO_3) (black, 96% U_3O_4)			
100 lb. lots. Black	lb.	..	2.75
Yellow	lb	..	1.50
Zinc oxide (ZnO)	lb	08½	.12
American process. Bags	lb	.05¾	.06
Zircon			
Granular (Milled .005-.02c higher)		07	07½-.08
Crude. Gran. (Milled .005-.02c higher)		03½	.04-.05